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INVESTIGATION OF LOW-TEMPERATURE SEMICONDUCTOR DEVICES

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ABSTRACT

The objectives of this investigation are to determine the characteristics of semiconductor devices at low temperatures.

The output characteristics of several currently available semiconductor devices and devices fabricated at MSFC were measured over a range of gate voltages. Large variations in low-temperature performance, not only from type to type, but from FET to FET of the same type were obtained.

By increasing the carrier concentrations at low temperatures through extra heavy doping, a MOSFET device was fabricated that operated at 4.2K. To verify the low-temperature operation of a heavily doped device, this procedure was repeated. Their noise spectrum was analyzed at 4.2K.

Suggestions were made as to possible fabrication methods, techniques, and other semiconductor materials that might improve the device characteristics at low temperatures.

A procedure for using an electric field to drift dopants through the insulating oxide to produce a very thin, heavily doped region under the gate of a MOSFET was initiated.

Capacitance as a function of voltage plots was suggested as a method for determining the level of dopant drift.

LIST OF FIGURES

Free carriers necessary for a semiconductor devices operation can be generated by thermal excitation.[1] The objective of this investigation was to determine the characteristics of several semiconductor devices at low temperatures.

Carrier freezeout occurs in most semiconductor devices as they are cooled to liquid helium temperatures. The infrared telescope detector, to reduce noise and increase sensitivity, will be cooled to 1.5 K. Semiconductor devices will be needed to operate at or near this 1.5 K and to amplify and record the signal received by the infrared telescope. Figure 1 is the current and voltage characteristics of a J230 transistor at 300 K. The typical transistor response was observed, and as the transistor is cooled to 77 K in liquid nitrogen, figure 2 shows a decrease in aplification.

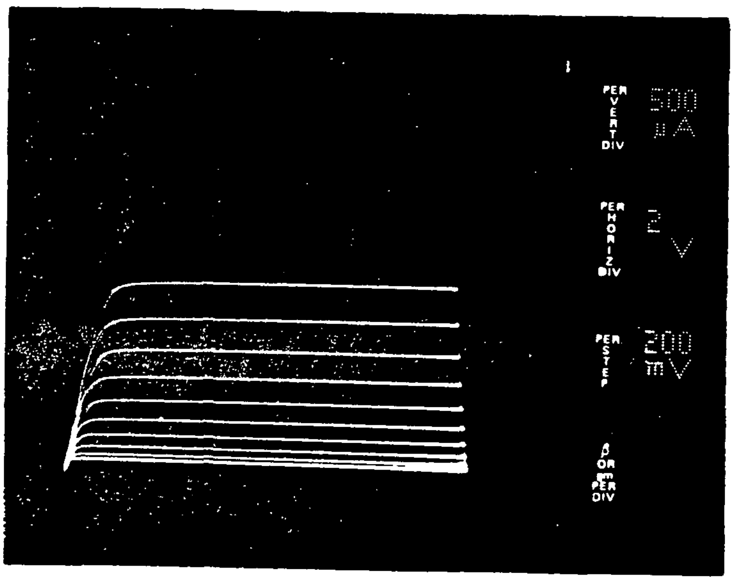

Figure 1. Current and voltage for a J230 at 300 K.

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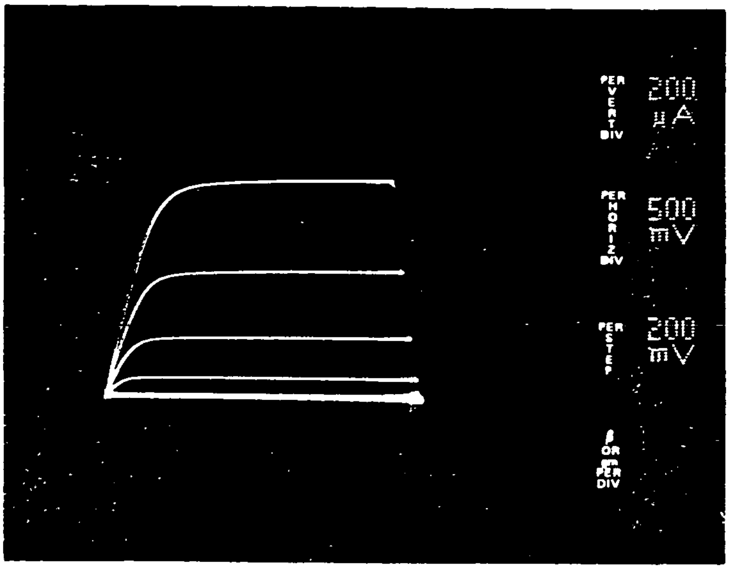

Figure 2. Current and voltage for a J230 at 77 K.

At 4.2 K, carrier freezeout has occurred and shows zero gain as shown in figure 3. The device returns to normal response as it is warmed to room temperature.

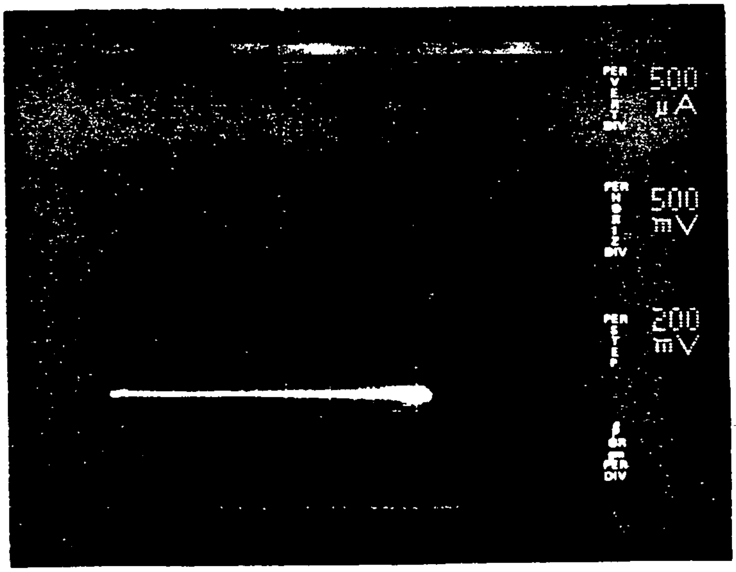

Figure 3. Current and voltage characteristics of a J230 at 4.2 K.

Five of these devices were measured at 4.2 K, and they all had zero gain with the detector at the same sensitivity as was used at 300K.

A 2N6483 FET semiuconductor was operated at 4.2 K at the University of Arizona.[2] As the temperature of the 2N6483 was lowered, its gain increased and then decreased. At the current sensitivity of 5 mA, no gain was observed. By increasing the current sensitivity to 0.5 mA, and by applying an offset voltage of 10 volts, the semiconductor operated as shown in figure 4.

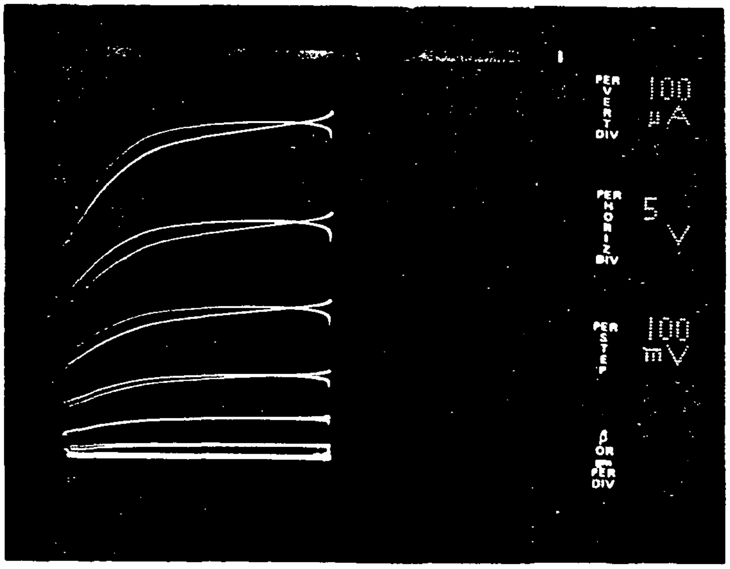

Figure 4. Current and voltage characteristics of a 2N6483 at 4.2 K.

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The hysteresis is a measuring instrument problem and not a characteristic of the semiconductor. This offset voltage increases the risk of the device failure and is a property that is not recommended.

Heavy doping can generate carriers in semiconductors[3] at low temperatures. A MOSFET semiconductor was built here at the Marshall Space Flight Center and labeled 3-2. Gate 4 was measured, and the results are shown in figure 5, figure 6, and figure 7.

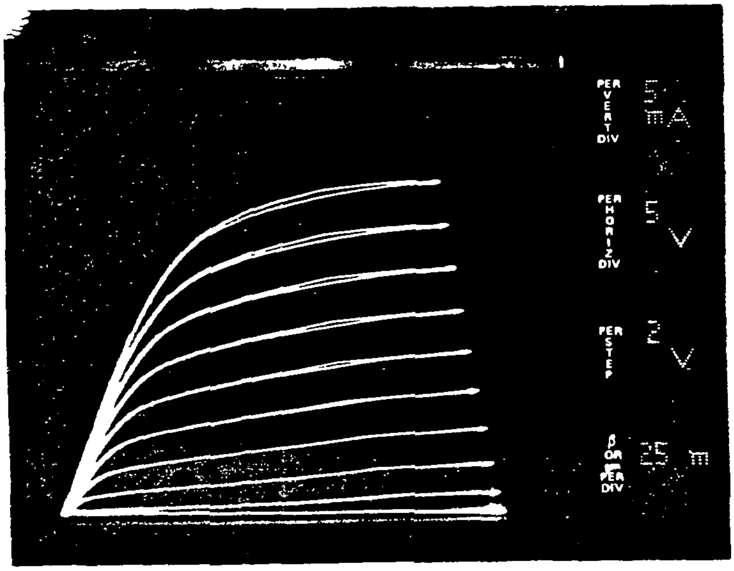

Figure 5. Current and voltage characteristics of gate 4 at 300 K.

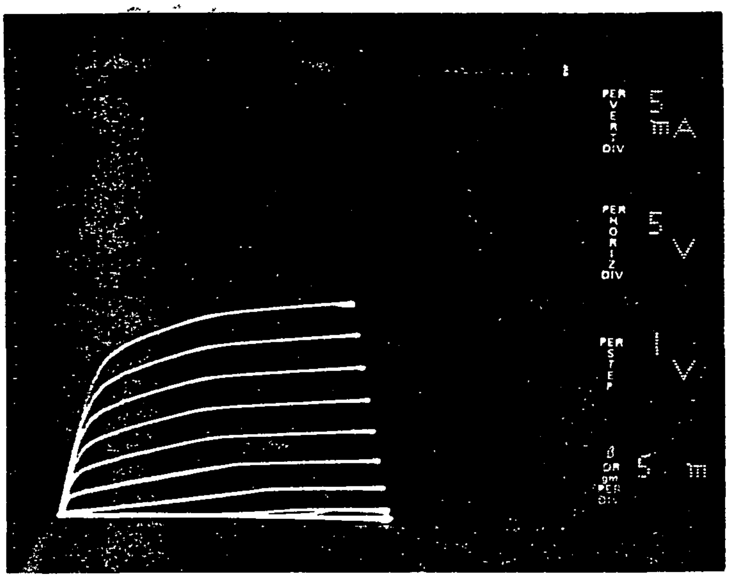

Figure 6. Current and voltage characteristics of gate 4 at 77 K.

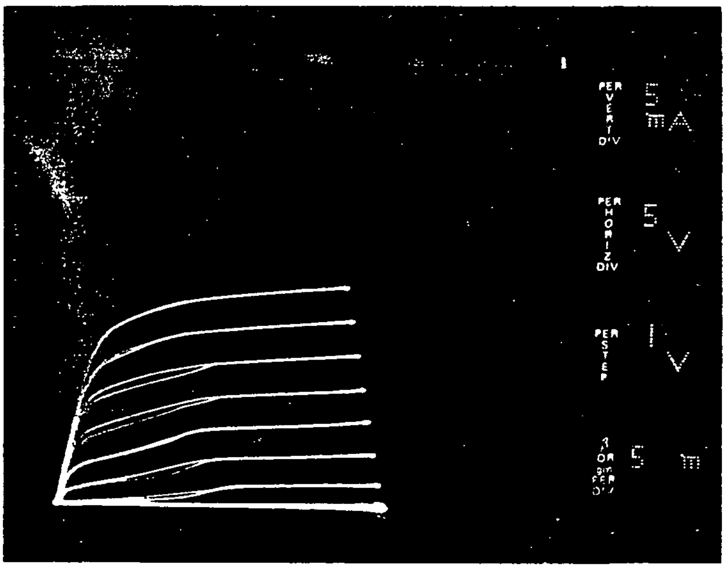

Figure 7. Current and voltage characteristics of gate 4 at 4.2 K.

The heavily doped p-channel semiconductor continues to operate at 4.2K. Figure 8 shows the curves produced by a 3N165 at 77 K.

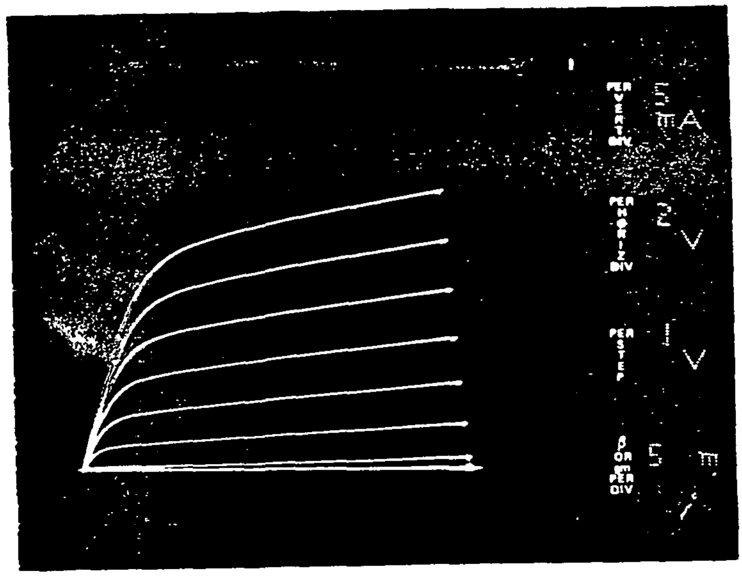

Figure 8. Current and voltage characteristics of a 3N165 at 77 K.

The calculated thermal noise for a TIXM12 is .16 nV/Hz and .26 nV/Hz[4] for the 2N6483 at 4.2 K, so thermal noise will be much smaller than the 1/f noise only at frequencies well above the infrared detector frequencies.

Cooling the 3N165 results in a gain amplification t 77 K. At 4.2 K, the device continues to operate as shown in figure 9.

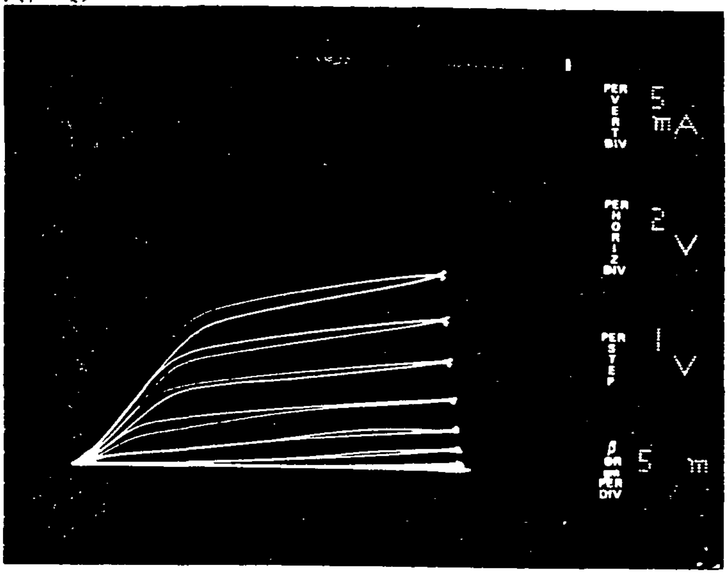

Figure 9. Current and voltage characteristics of a 3N165 at 4.2 K.

The 3N165 continues to operate without an offset voltage and has a gain equivalent to its gain at 300 K.

My recommendation is to:

Repeat the fabrication procedures to build another heavily doped semiconductor to check the reproducibility of the process.

Fick's law gives the relationship between the diffusion distance of an ion and time as an electric field is applied to a solid that contains ions.[5] I recommend the construction of an apparatus that may be used to apply an electric field to dopant ions placed on the gate oxide of a MOSFET. This electric field will diffuse the dopant ions into the gate channel and form a p-channel that is shallow and will not require an offset voltage to operate at low temperatures.

The use of voltage vs. capacitance measurement before and after heating be used to measure the dopant drift.

Measurements be continued on devices that have been found to operate, at low temperatures, by others such as the RCA 3N139,[5] SiAs JFET's,[6] and TIXM12.

The semiconductor devices that operate should have their noise spectrum measured.

The noise spectrum should be measured for the semiconductor devices that operate at 4.2K.

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